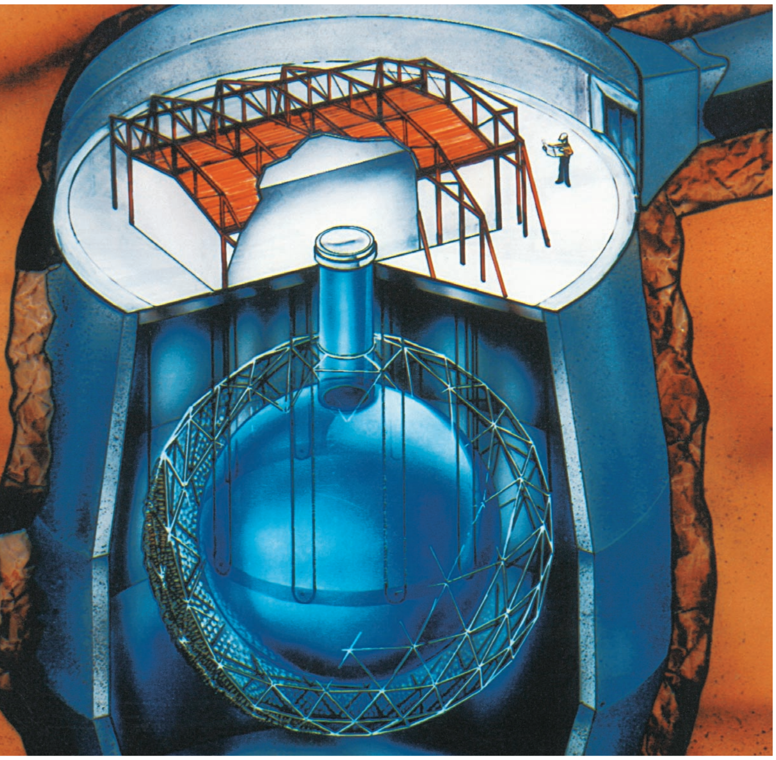
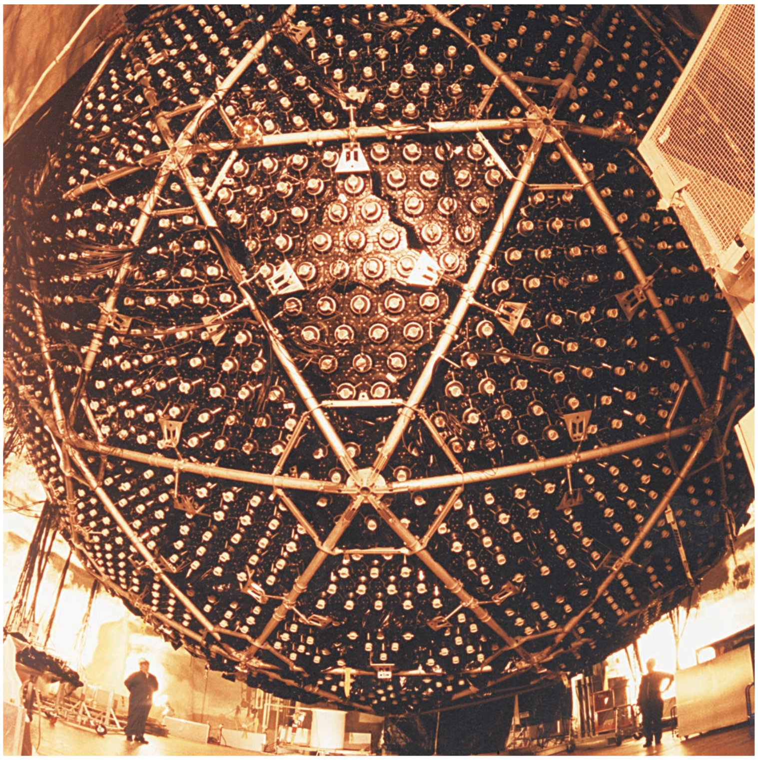
Not Your Average Observatory





When you think of an observatory, you probably think of a large telescope on a remote mountaintop that collects light from stars and galaxies. You're not likely to think of 1000 t of heavy water at the bottom of a mine shaft, 2 km below Earth's surface. But that's exactly what you will find at the Sudbury Neutrino Observatory — also known as SNO — where scientists are trying to detect a wily, elusive particle called the "neutrino."

The existence of the neutrino was first predicted in 1931 by Wolfgang Pauli, when certain nuclear reactions appeared to be violating the laws of conservation of energy and momentum. Rather than modify or discard the law, Pauli suggested that an unseen, chargeless and probably massless particle was carrying away some of the energy and momentum. Italian physicist Enrico Fermi later named this mysterious particle the "neutrino," which means "little neutral one" in Italian.

Not Your Average Particle

Like the photon, the neutrino is produced in enormous quantities by nuclear reactions in the centres of stars, such as the Sun. They travel at close to the speed of light and carry away substantial amounts of energy from the star's hot core. Just as photons are collected by telescopes to analyze the processes that create them, neutrinos are observed in order to understand what's happening in the centres of stars. By counting neutrinos, physicists learn about the rate of fusion reactions in stellar cores. Although there are now known to be three types of neutrinos, stars produce the type known as the "electron-neutrino."

Unlike the photon, which interacts strongly with matter, the neutrino scarcely interacts with matter at all. Some 60 billion neutrinos pass unhindered through each square centimetre of your body each second. A beam of neutrinos could sail through a shield of lead 1 light-year (10 thousand billion kilometres) thick without being reflected or absorbed. This is why it took physicists almost 30 years after Pauli's prediction to verify the neutrino's existence.

Detecting a Neutrino

Detecting a neutrino is tricky, because it passes right through photographic film and electronic detectors, the devices that register photons. This is where heavy water is useful. Heavy water is made up of oxygen and deuterium, which is a hydrogen nucleus with an added neutron. It's about 10% heavier than "light" water, and its symbol is D_2O. Occasionally, in one of several possible reactions, neutrinos will transform a deuterium nucleus into a pair of protons and an electron. Neutrinos enter the tank with super-high energies and, because energy is conserved, the electron produced in the reaction will be jettisoned at speeds faster than the speed of light in water. It's like a high-speed crash, where even the debris of the collision flies out at high speed. As the energetic electron slows down in the water, it emits a flash of light, or a shock wave — the optical equivalent of a sonic boom. About 500 to 800 photons will be generated in the flash, with a total energy proportional to that of the incident neutrino.

Outside the tank of heavy water, several of the 10 thousand photomultiplier tubes will detect this tiny light flash. These photomultipliers comprise the main part of the detector. Together, they are about 200 000 times more sensitive than the human eye. This sensitivity is required because the flash of light is only as bright as the flash of a camera seen from the distance of the Moon! So, even though the neutrino is not detected directly, the product of its interaction is. Despite the 1000 t of heavy water, only about 10 neutrinos are detected per day.

One Mystery Solved

One longstanding problem that the Sudbury Neutrino Observatory investigated was the significant difference between the number of predicted neutrinos based on solar models and the number of neutrinos that were actually observed. Was the difference due to observation errors in the experiments and detectors, which were begun in the 1970s, or to errors in the scientific model calculations? Despite refinements in both over nearly 30 years, the difference persisted. Why?

The unexpected answer, which SNO helped provide in June 2001, was due to the neutrinos themselves. Because the Sun generates only electron-neutrinos, the earlier experiments were designed to detect only this type of neutrino, and not the other two types. Recent results from SNO, together with those of another detector in Japan, indicate that after neutrinos are generated in the Sun, they oscillate between the three types while they travel. Because of its ability to detect different types of neutrino reactions, SNO is sensitive to all three types of neutrinos, and it was able to show that earlier experiments simply missed the transformed neutrinos — but they were there all along.

For such transformations to take place, the neutrino must have a tiny mass, contrary to what was originally thought. SNO has measured this mass to be roughly 60 000 times less than that of an electron. What this new result means for elementary particle theory remains to be seen. How the neutrinos change type is also still not understood, but with continued monitoring of incoming neutrinos, SNO hopes to shed light on that too.

Making Connections

1. Could neutrinos enter the Sudbury Neutrino Observatory after passing through the far side of Earth, that is, on their way back out into space?
2. How do the laws of conservation of energy and momentum apply to reactions between particles?
3. How does the SNO differ from other neutrino observatories worldwide?